STRUCTURAL ANALYSIS OF BRIDGES AND PILE FOUNDATION SUBJECTED TO SEISMIC LOADS

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Abstract - *An Effect of various materials of pile foundation of bridges in response of the seismic loading condition has to be monitored. Such an analysis was required to verify the performance of each structure acting under seismic loads. In this study, a numerical model is developed to evaluate both bridges and pile foundation performance with respect to varying seismic loading conditions. Specifically speaking to evaluate the performance of various structural materials used as pile foundation for bridges against seismic loads. The vibrational behavior of the bridge was also evaluated on the basis of seismic loads on the structure. Furthermore, pile foundation of the bridge was modeled along with combination of soil in order to analyze the behavior of the structure with soil. Also the bridge pile foundation of different structural material namely structural steel, carbon fibre reinforced steel and epoxy fibre reinforced steel were modeled using ANSYS software. It was observed that Carbon fibre reinforced structural steel is superior in performance as compared to that of the structural steel and epoxy fibre reinforced structural steel in both pile foundation as well as development of bridge structure. Maximum nodal displacement for bridge structure with respect to seismic load conditions for different materials were Carbon fibre structural steel as 63.104 mm, Epoxy fibre structural steel as 69.992 mm and Structural steel as 70.091 mm respectively.*

Key Words: ***Carbon fibre structural steel, Epoxy Fibre Structural Steel, ANSYS.***

1 INTRODUCTION

These soil pressures may come from pile settlement, soil swelling, or passive resistances brought on by lateral stresses the superstructure transmits to the pile caps. If the earth directly beneath a building's base is incapable of supporting the structure, piles may be used as a foundation. A pile foundation may be taken into consideration if the findings of the site study indicate that the shallow soil is weak and unstable, or if the size of the predicted settlement is unacceptable. Additionally, a cost estimate can show that a pile foundation is less expensive than any other ground improvement costs that are being evaluated. There are various ways to arrange piles so they can support loads that are placed on them. It is possible to build vertical piles to support both lateral and vertical loads. Raking heaps and vertical piles can be used in combination, as needed, to sustain both horizontal and vertical forces. If a pile group is subjected to vertical force, the total load is considered to be divided by the number of piles in the group, which is used to calculate the distribution of load on a single pile that is a part of the group. But if a group of piles is exposed to lateral load, eccentric vertical load, or a combination of vertical and lateral load, the group may experience moment force.

Due to the increase in urban population, underground rail transit has developed into one of the main modes of transportation [1]. The majority of subway stations, which act as the hubs of transportation for underground rail networks, are situated in hilly, heavily populated urban regions. One of the biggest issues that regularly affects subway stations during construction is ground surface settlement [2-4]. These buildings usually have deep piling foundations, which might impede the construction of pipelines and other underground constructions like subways [5]. Pile foundations have been constructed for numerous projects, including high-rise structures. It is frequently necessary to use pile foundation underpinning to transfer the existing pile foundation's weight properly in order to maintain the stability of the top construction technology. Thus, underground transport infrastructures, like subway tunnels, are progressing smoothly [6].

2 LITERATURE REVIEW

In order to get a actual knowledge of the various seismic design and pushover investigation approaches, various research articles, design codes and relevant books were scrupulously studied to understand the effect of seismic parameters on design & detailing of RC buildings. This helped in deciding obligatory modeling methods and parameters to be used in seismic investigation and comparisons. Kumar and Rao (2002) have carried out corresponding stationary investigation for a five (G+4) storied RC building in order to match up to the variation of percentage steel when the building is designed for gravity loads as per IS 456:2000 and when designed for earthquake forces in all the seismic zones as per IS 1893:2002. Samyog (2013) has done a study which involves cost comparison of RCC Columns in identical buildings based on number of Stories and Seismic

Zones. This work presents that the detailing of columns of a building covering certain plinth area varies for a combination of storey and seismic zone. Another facet of this study involves performance evaluation of the designed buildings for various seismic zones and detailing provisions using computer based "PUSH-OVER" Analysis. The need of such an exercise has been well illustrated by Ghosh and Munshi (1998) in which it has been stated that the aim of the design codes is cardinally to minimize the life hazards and Athanassiadou analyses two ten-storeyed plane stepped frames and one ten-storeyed regular frame which were designed as per Euro code 8 for the high and medium ductility classes. In this work the Inter-storey drift ratios of the frames and plastic hinge formation in columns were monitored. In this work, the results of pushover analysis were presented using "uniform" load pattern as well as "modal" load pattern.

Lu et al. [8] discovered that the SAP consolidation settlement is positively correlated with the PSSR. The settlement characteristics of the stratum in the construction process are studied and determined the reasons for the difference between the numerical and field monitoring results [13]. Experimental study and DEM simulation carried out of the push-up load tests, where sand plugs inside steel pipe piles were pushed upwards using a rigid platen; test results showed that the push-up force increased significantly with increasing aspect ratio and sand relative density [15]. Xu et al. [20] conducted a series of theoretical analysis and numerical simulations of the entire construction process to verify the rationality of the scheme and to reduce the potential construction risk of the technology. Park et al. [21] proposed and verified the application of the modified underpinning method, which can reduce the construction period by 1.5 times and the construction cost by 1.2 times compared with the conventional pile cutting technology. Horikoshi et al. [36] carried out a series of centrifuge tests on piled raft models embedded in sand subjected to horizontal and vertical loadings to study the load settlement behaviour and the load sharing characteristics between the piles and the raft. The effect of the rigidity at the pile head connection on the piled raft behaviour was also explored. Finn and Fujita [49] used an equivalent linear model for soil and beam elements for piles in their 3D finite element simulations of piles in liquefiable ground. Cheng and Jeremic [50], Lu et al. [51] and Chang et al. [52] used plasticity models [53,54] for sand in their simulation methods and used various different techniques to connect the beams representing the piles to the soil elements in order to reflect the geometric properties of the piles. Wang et al. [55] developed a fully 3D simulation method for piles in liquefiable ground by using second-order hexahedron elements for piles to capture both its physical geometry and bending and used a unified plasticity model for large post liquefaction shear deformation of sand [56] to give a good account for the behaviour of saturated sand under seismic loading. The simulation method developed by Wang et al. [55] was validated against a series of centrifuge shaking table tests on single piles in liquefiable ground, and the numerical simulation results showed good agreement with the test measurements.

3 OBJECTIVES AND PROBLEM STATEMENT

Efficiency of pile foundation of bridges against the action of seismic loads has always been a major problem. Due to lack of interpretation and knowledge of parameters effecting performance of bridges foundation structures under seismic loading, design of the bridges under earthquake is hampered. Development of a numerical model becomes very essential which can illustrate the phenomenon of earthquake properly and with less cost it makes building react approximately to same conditions it has to undergo at practical level.

- To study performance of bridge pile foundation of structural steel against seismic loads in different zones.
- To study performance of bridges under seismic loads
- To study the vibration behavior of the bridges under seismic loading conditions
- To evaluate the performance of various structural materials used as pile foundation for bridges against seismic loads

4 METHODOLOGY

The bridge is modeled first with seismic loads in order to analyze different behaviour of the structure with regards to seismic loads. The vibrational behaviour of the bridge was also evaluated on the basis of seismic loads on the structure. Furthermore, pile foundation of the bridge was modeled along with combination of soil in order to analyze the behaviour of the structure with soil. Also the bridge pile foundation of different structural material namely structural steel, carbon fibre reinforced steel and epoxy fibre reinforced steel were modeled using ANSYS software. Different bridge structures were individually subjected to strong and typical earthquakes, or seismic stresses, from various zones in India. Seismic loads of various zones were tabulated, along with a graph of their time-acceleration. Such values served as the boundary conditions for the loading conditions applied to the structure used in the relevant study. It was noted that seismic research was carried out with the understanding that the building's foot was securely planted in the ground and that its terminal connections were fastened. The seismic investigation of the building revealed that gravity loads also had a significant impact.

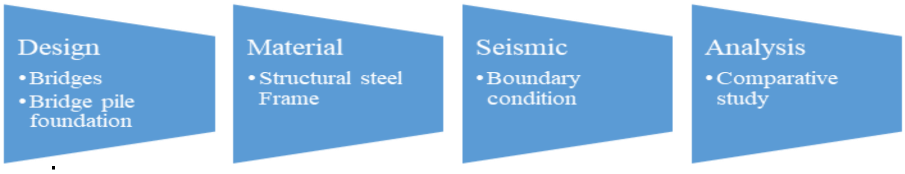

Figure 1 Design morphology of Bridge pile foundation subjected to seismic loads

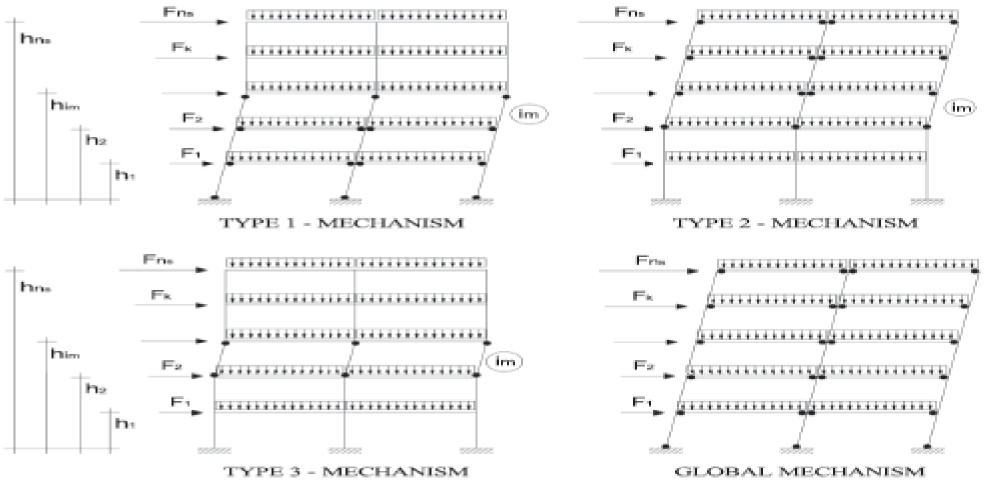

Figure 2 Collapse mechanism of structure under seismic loading

Figure 4.1 shows the morphology of the design that is it represents the methodology of the project it was eventually observed that the beginning and the most important step of analysis of any bridge is modeling of the bridge with its cross-sectional frame and piles. In this stage it was realized that three different forms or shapes of bridge pile structure were presented in the work It was observed that the column size is of 0.35 m x 0.45 m, and the beam size is 0.23 m x 0.45 m. material to be used was presented in the form of:

Unit weight of RCC: 25 kN/m³
Unit weight of Masonry: 20 kN/m³ (Assumed)
Modulus of elasticity, of concrete: $5000\sqrt{fck}$
Poisson's ratio: 0.17

The depth of foundation is 2 m and the height of bridge is 5 m.

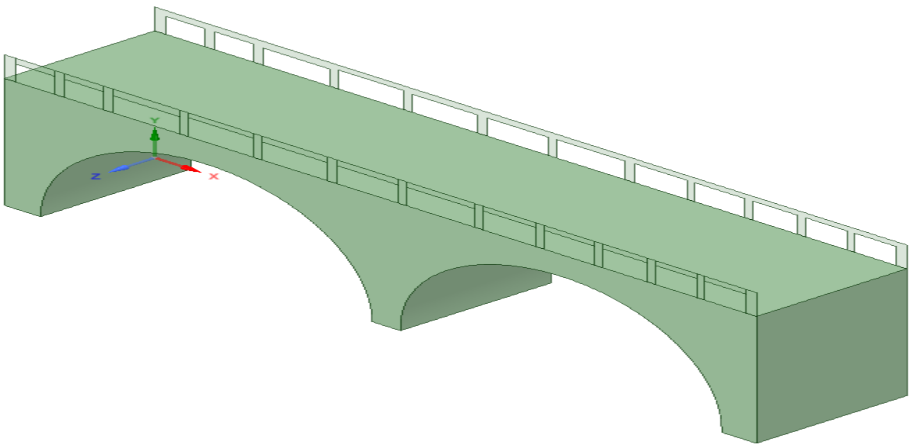

Figure 3 Isometric view of bridge structure

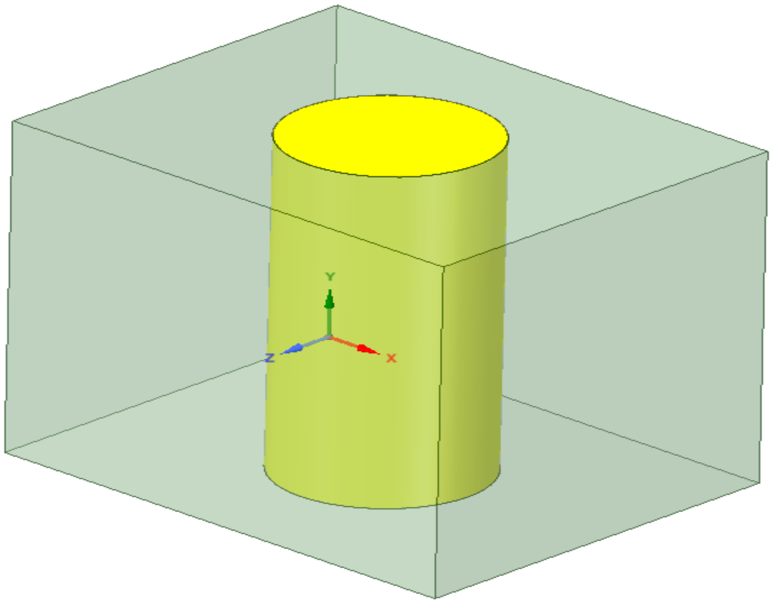

Figure 4 Pile foundation inside soil

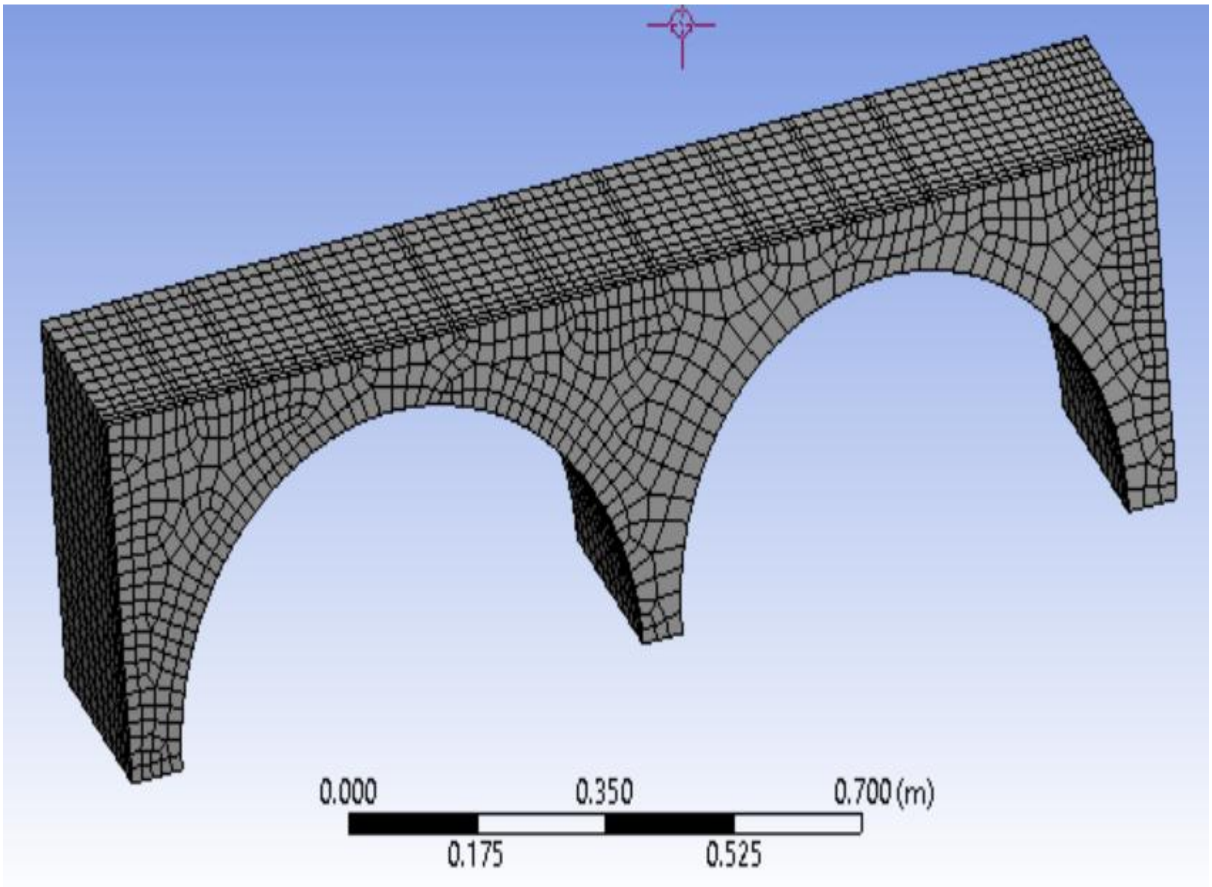

Figure 5 Meshed model of Bridge

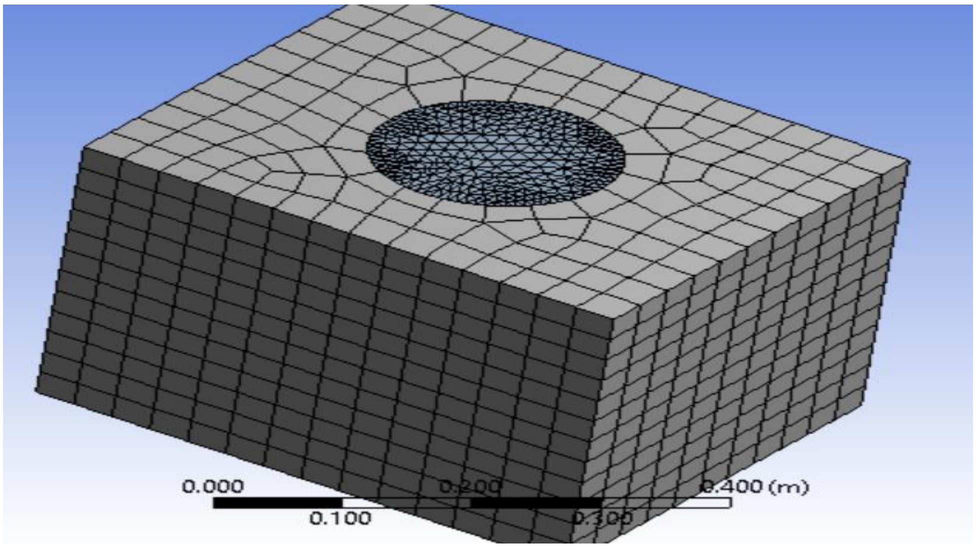

Figure 6 Meshed model of piles with soil

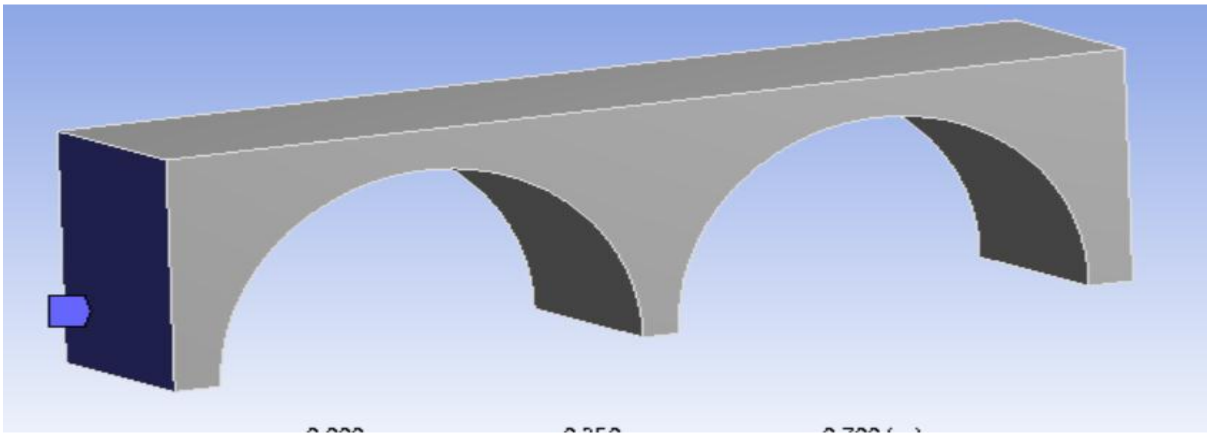

Figure 7 Boundary condition of Pier for simulations

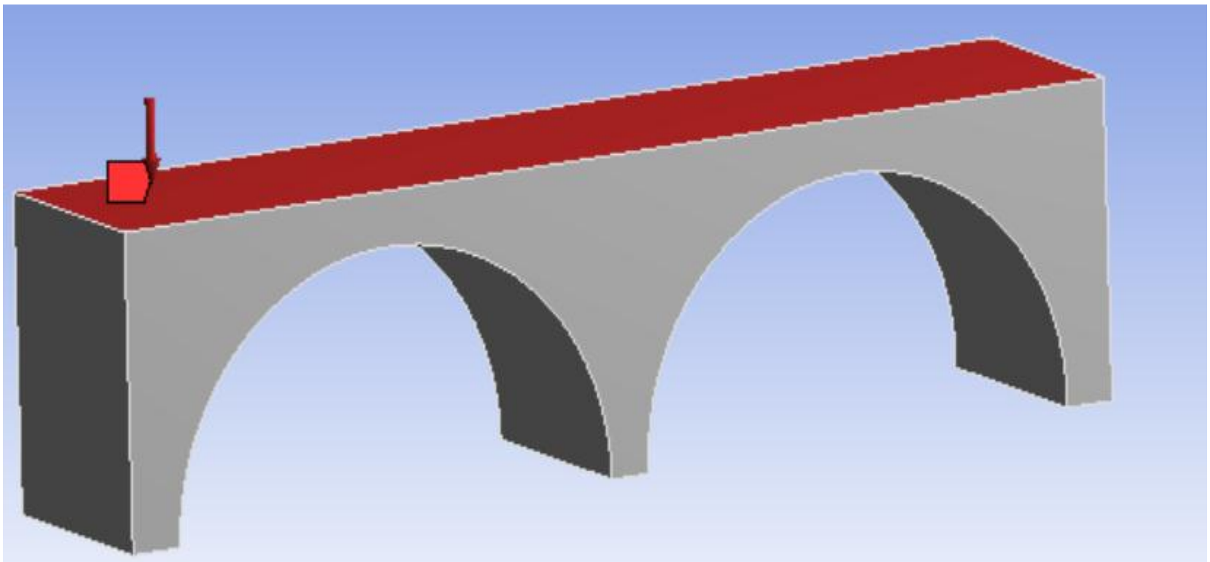

Figure 8 Boundary condition of Bridge for simulations

Figure 4.8 shows a boundary and loading condition of bridge structure which was also subjected to seismic loads in order to analyze the performance of such a structure under such varying and conditional load conditions. The bridge structure was made up of structural steel.

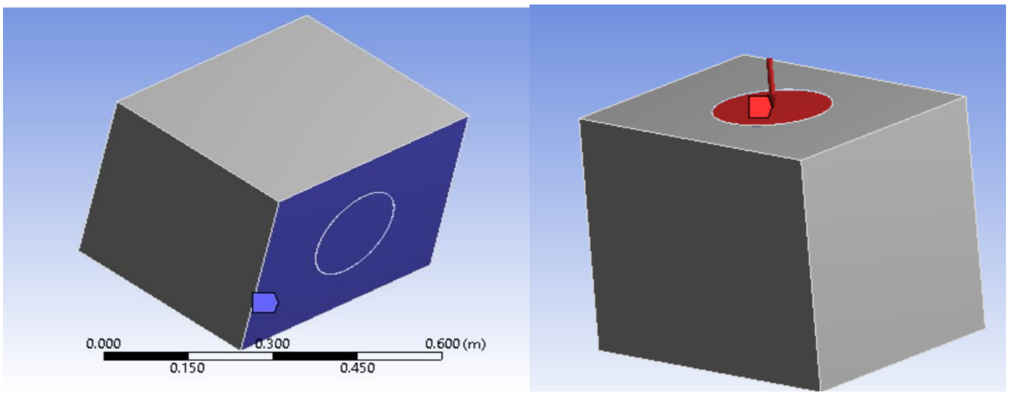

Figure 9 Loading conditions of pile with soil foundation

Figure 4.9 shows a loading condition of pile with interaction of the soil which was also subjected to seismic loads in order to analyses the performance of such a structure and also to evaluate how the interaction between the soil and pile usually happens at the time of loading and varying conditions. Furthermore, pile is made up of different structure like structural steel, carbon fibre reinforced steel and epoxy fibre reinforced steel.

4.1 Boundary Conditions

One of the most important ways to pre-process a simulation task is to provide boundary conditions. The frame system boundary conditions assumed the base of the column to be fixed. Adhesive contact was provided between all faces of the frame pillars that were joined together. Separation between the joints of the structure is not allowed so that the load is fully transmitted throughout the structure. A gravity load was applied to the structure to account for the effects of building inertia and gravity during the seismic analysis. Seismic analysis was performed as an explicit dynamic analysis. Building frame loads were provided in the form of time acceleration history plots for different seismic zones.

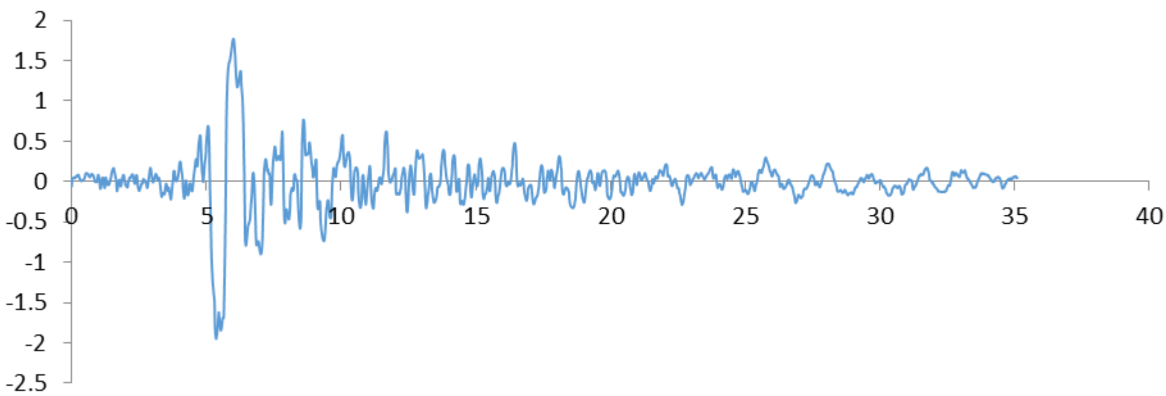

Figure 10 Time vs acceleration graph for Zone III

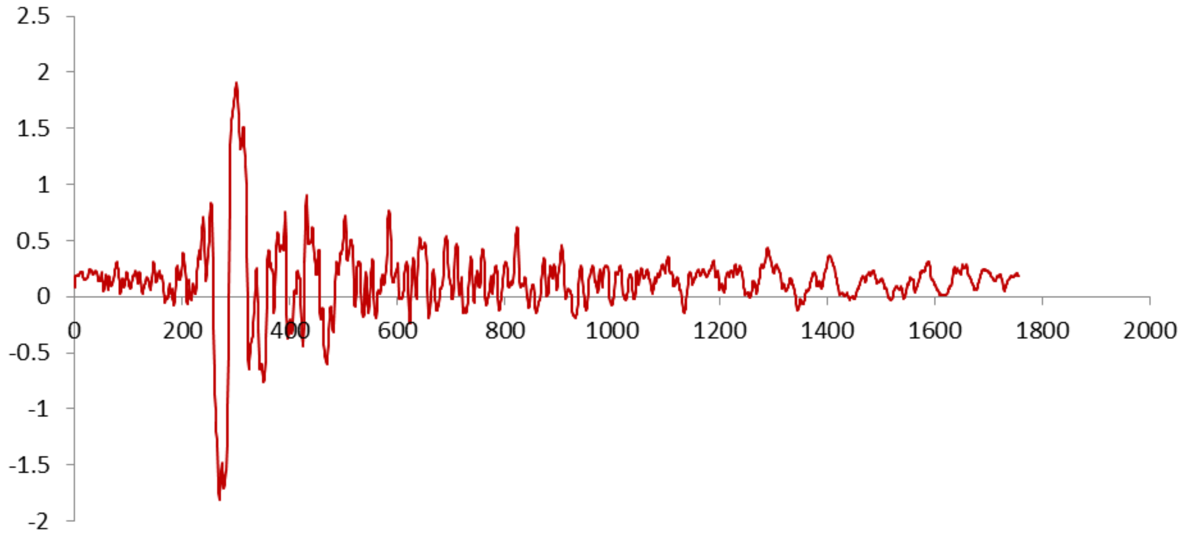

Figure 11 Time vs acceleration graph for Zone IV

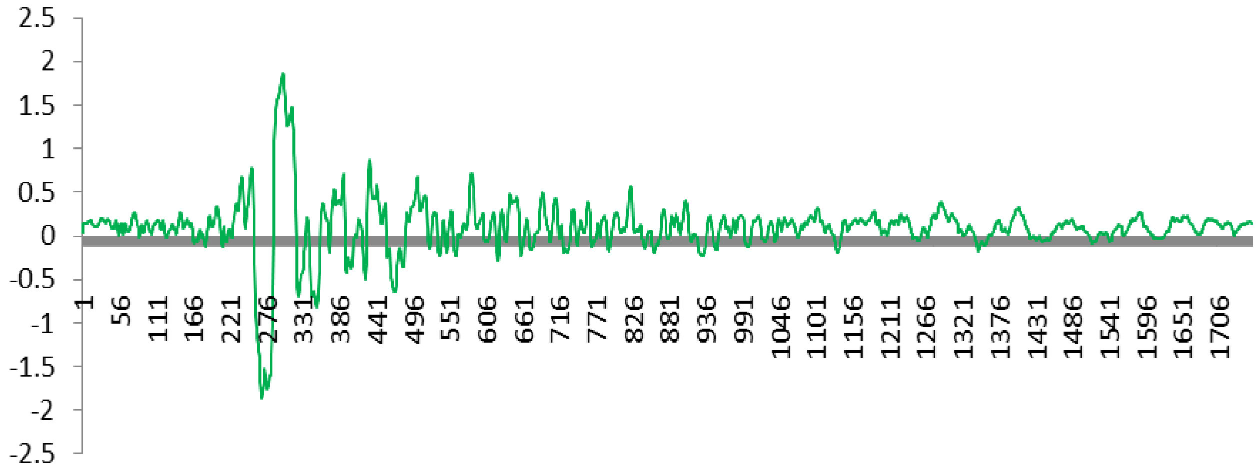

Figure 12 Time vs acceleration graph for Zone V

Above graphs represent the time acceleration graph used for a particular Indian regional earthquake zone namely Zone III, Zone IV and Zone V.

5 RESULTS AND DISCUSSION

Bridge structure and pile foundation with soil were subjected to seismic loading conditions. Bridge structure and pile foundation with soil are the two different conditions of the structures which were subjected to high dynamic seismic loads. Seismic loads applied were also varied in the structure with the aid of time acceleration graph obtained from the history of different zones of earthquake in India.

5.1 Modes of Deformation of Bridge Structure

It was observed that bridges start to behave very nonlinearly under the influence of very dynamic seismic loads. Structural nonlinearity occurs in tall bridges regardless of the shape of the building. In case of seismic loading of the structure resulting from different earthquake zones, the non-linearity of the structure remains almost the same, only the size of the deformation varies.

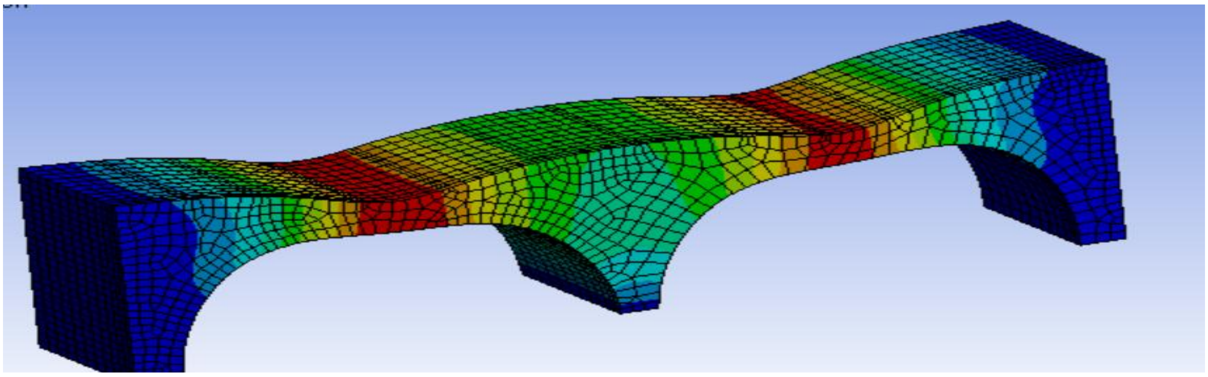

Figure 13 Displacement variation in Bridge structure

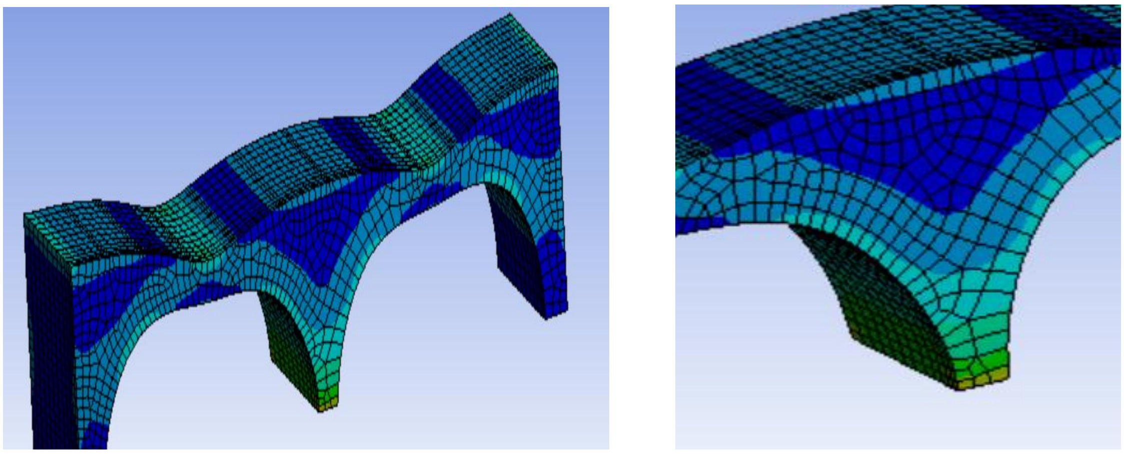

Figure 14 Stress variation in bridge structure

It was observed that for bridge structure with structural steel seismic analysis has to be performed by dynamic modes then only accurate results were possible. Figure 5.2 shows the modes of deformation of the structure when subjected to highly unstable seismic loads. It was observed that structure undergoes a to and fro motion in the horizontal direction with time while the magnitude of the displacement was directly proportional to the intensity of the earthquake. It was clearly visible that the structure (of any shape) has higher deformation in bridge structure with structural steel as compared to bridge structure with conventional structural steel.

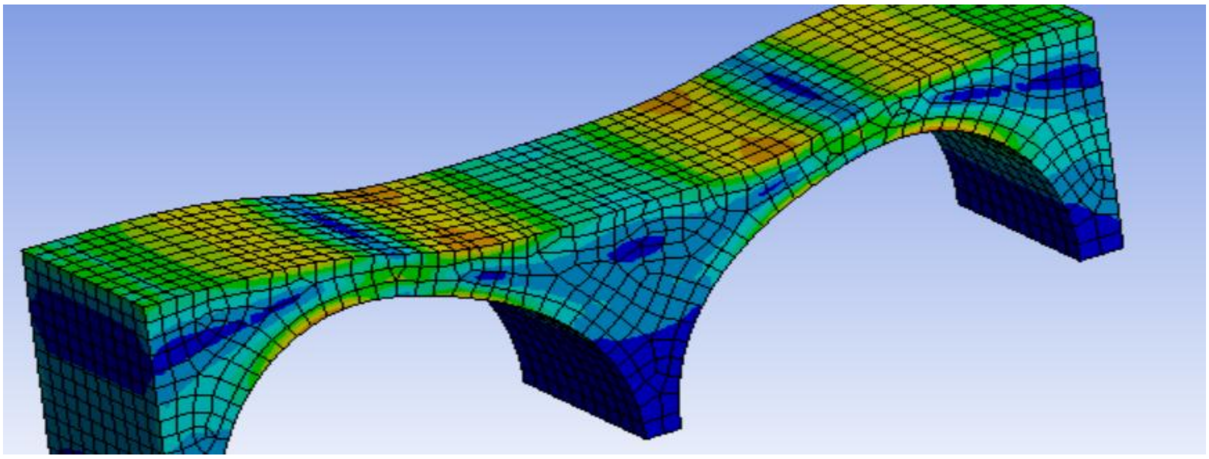

Figure 15 Stress variation in bridge structure of carbon fibre reinforced steel

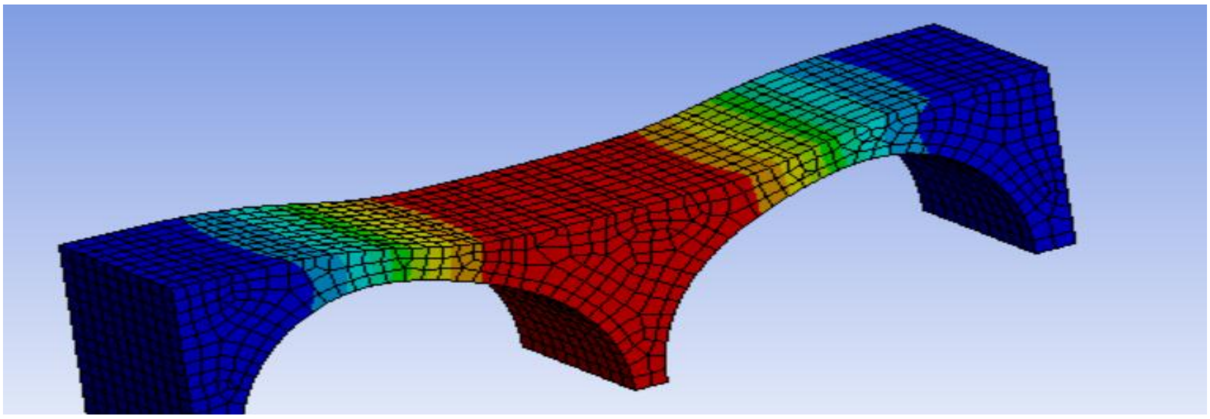

Figure 16 Displacement variation in carbon fibre reinforced steel Bridge structure

5.2 Bending Moment

When the magnitude of the seismic loads applied were as per that of time acceleration graph of Zone III. All three different types of the bridge structure normal structural steel, carbon fibre steel and epoxy fibre structural steel bridges were subjected to same earthquake load as per Zone III according to IS codes. It was evident that structural steel bridge frame tends to have maximum bending moment on comparison to other two types of structure.

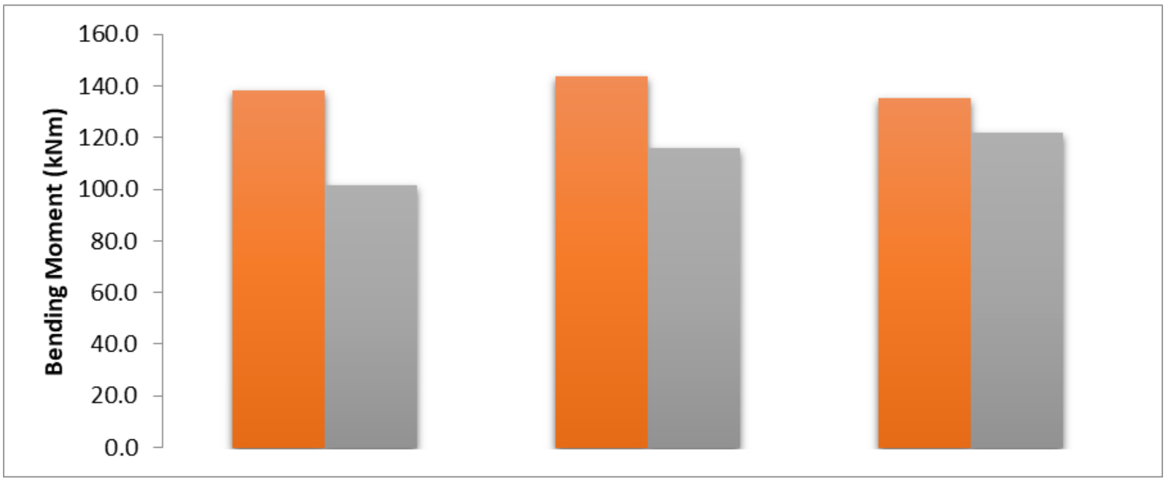

Figure 17 Bending moment in buildings in Zone III

5.3 Shear Forces in Seismic Loads

When the magnitude of the seismic loads applied were as per that of time acceleration graph of zone III. All three different types of the bridge structure normal structural steel, carbon fibre steel and epoxy fibre structural steel bridges was subjected to same earthquake load as per zone III according to IS codes. It was evident that structural steel tends to have maximum shear force on comparison to other two types of structure.

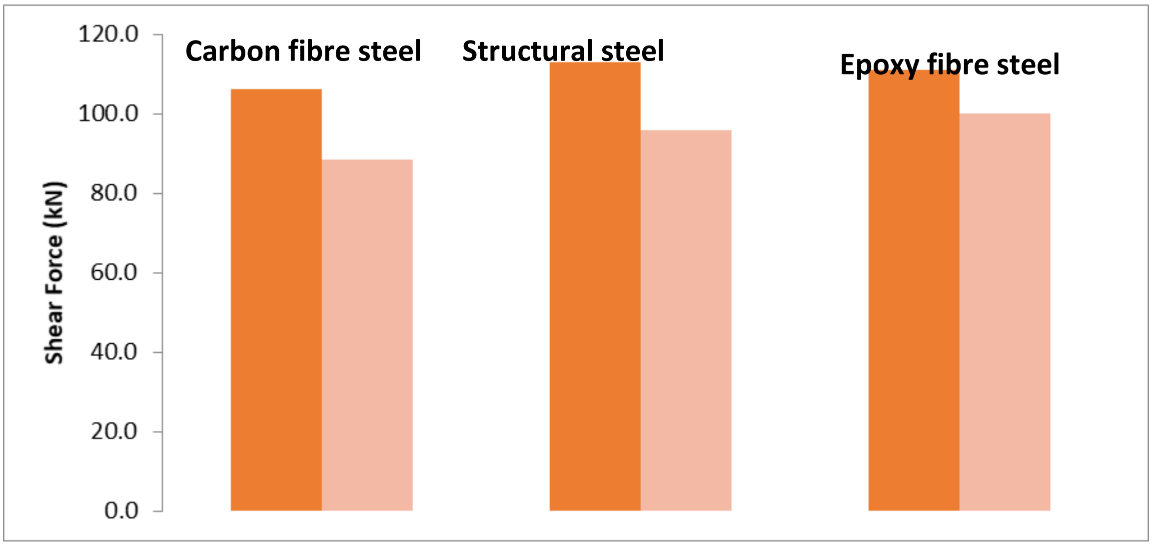

Figure 18 Maximum shear force in Zone III

5.4 Displacement in Bridges When Subjected To Seismic Loads

When the magnitude of the seismic loads applied were as per that of time acceleration graph of zone III. All three different types of the structure bridge structure normal structural steel, carbon fibre steel and epoxy fiber structural steel bridges as subjected to same earthquake load as per zone III according to IS codes. It was evident that structural steel tends to have maximum displacement on comparison to other two types of structure.

Table 1 Nodal displacement in x direction

MAXIMUM NODAL DISPLACEMENT (mm) IN ZONE III			
	TYPE OF STRUCTURE IN X DIRECTION		
	Carbon fibre str.	Epoxy Fibre steel	Structural steel
Bridge structure	63.104	69.992	70.091

Table 2 Nodal displacement in z direction

MAXIMUM NODAL DISPLACEMENT (mm) IN ZONE III			
	TYPE OF STRUCTURE IN X DIRECTION		
	Carbon fibre str.	Epoxy Fibre steel	Structural steel
Bridge structure	63.104	64.928	70.091

It was observed from Table 5.1.and 5.2 that the maximum displacement of the structural steel frame tends to have the largest nodal displacement in both the x and z directions compared to the other two structural types. The structural steel frame therefore begins to behave more unstable when exposed to high dynamic seismic loads, while the other two frame types remain more stable.

Factor of Safety of the structural steel bridge structure was found out to be minimum of 2.1 which will be considered at the situation of the seismic load. Furthermore, the carbon fibre reinforced steel structure and epoxy fibre reinforced steel structure will have factor of safety of 3.8 and 3.1 respectively. Figure 5.7 shows the factor of safety pattern of the structural steel structure with respect to seismic loads.

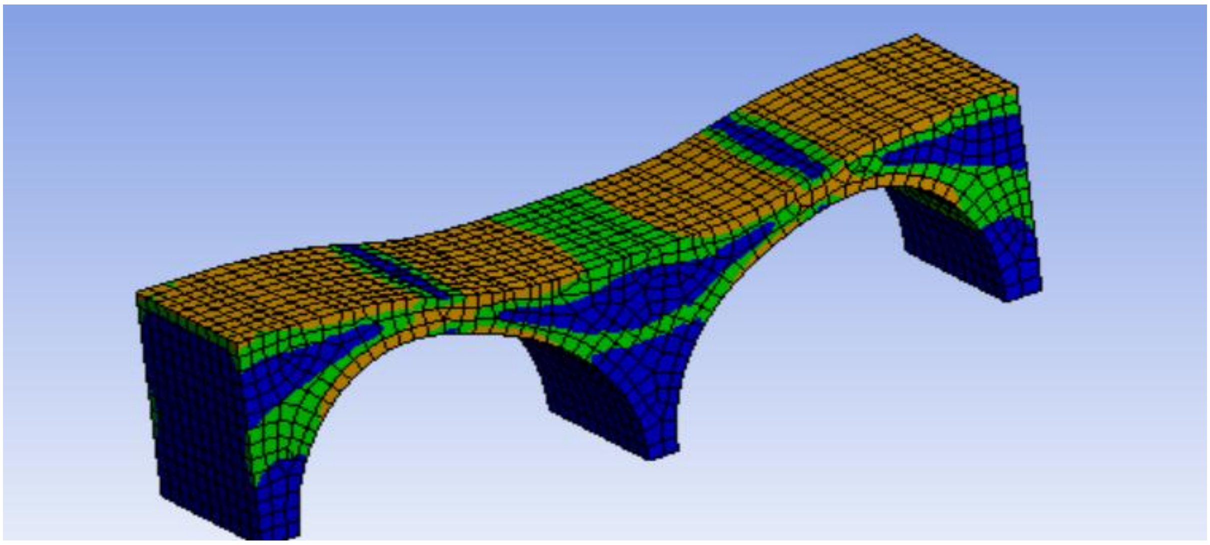

Figure 19 FOS pattern for Structural Steel Bridge

5.5 Design of Pile Foundation with Soil

In this case, the design of pile foundation used in the bridge has been separately analyzed in order characterize the behaviour of the pile foundation with soil under the action of seismic loads. The soil model was modeled with the form of a cuboidal box of 1mx1mx1m and the pile foundation rod of 1 m length and 350 mm diameter. The pile was characterized with different materials. Loading condition of pile with interaction of the soil which was also subjected to seismic loads in order to analyses the performance of such a structure and also to evaluate how the interaction between the soil and pile usually happens at the time of loading and varying conditions. Furthermore, pile is made up of different structure like structural steel, carbon fibre reinforced steel and epoxy fibre reinforced steel.

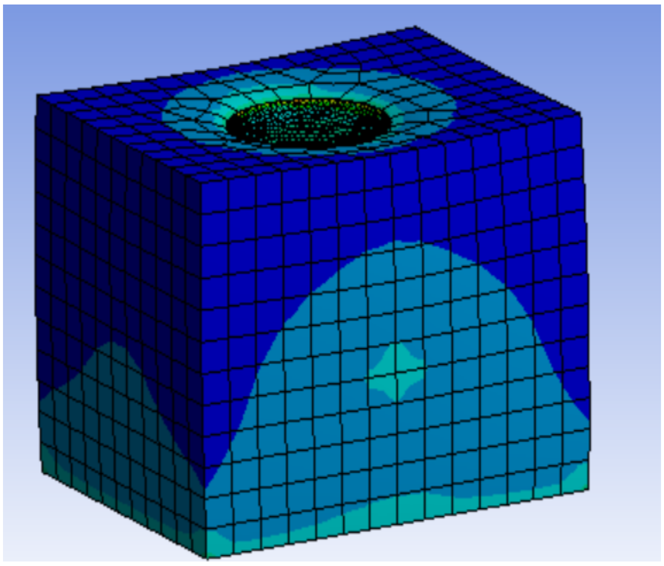

Figure 20 Stress pattern in piles and soil with foundation for structural steel

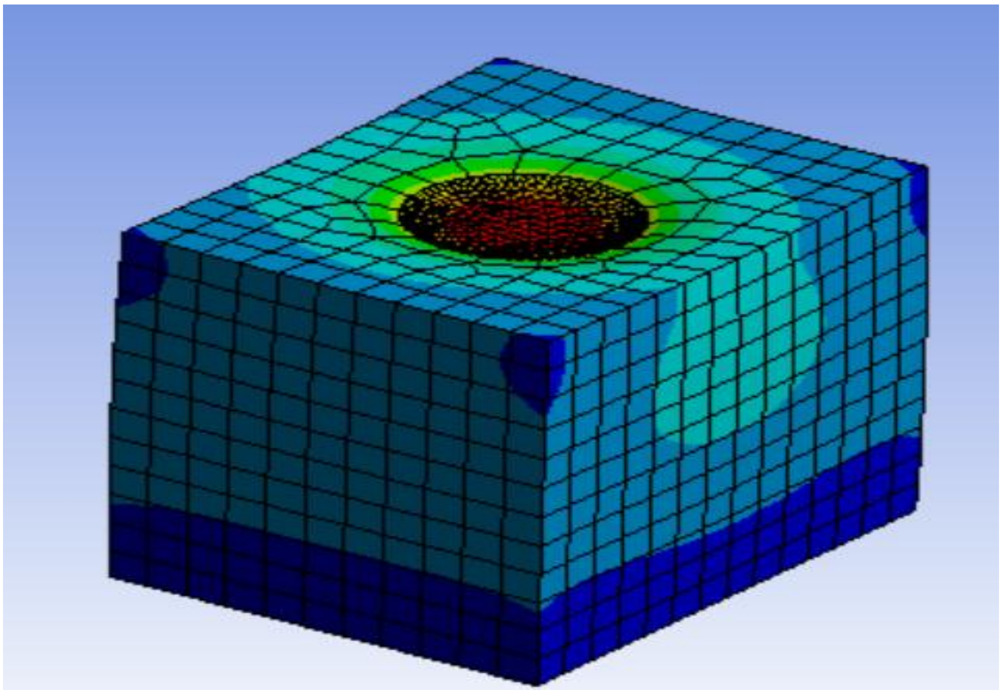

Figure 21 Displacement pattern in piles and soil with foundation for structural steel

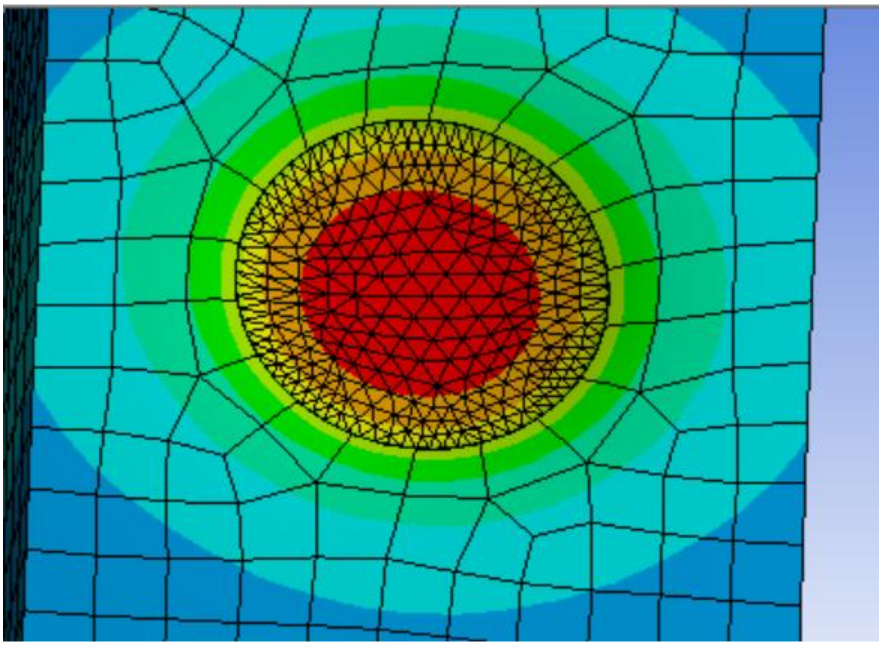

Figure 22 Displacement pattern in piles and soil with foundation for structural steel (Close view)

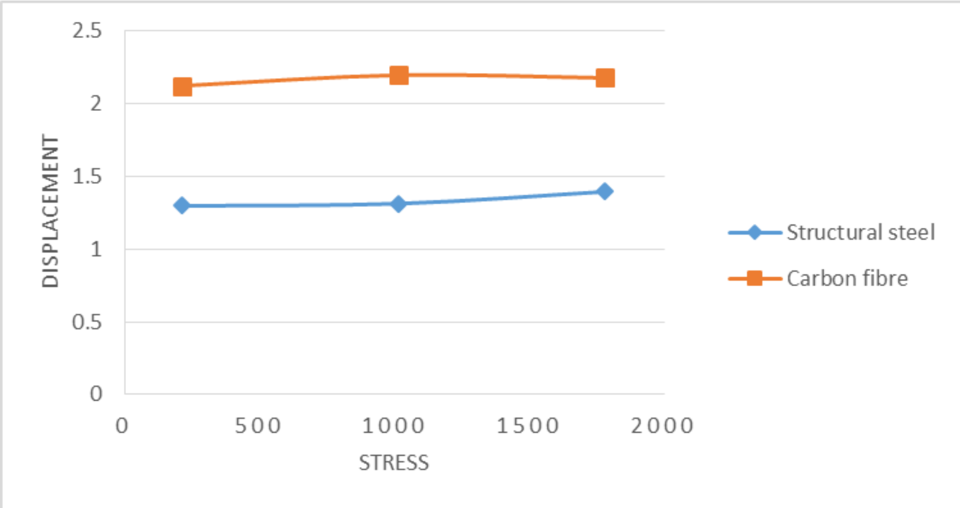

Figure 23 Variation between Carbon fibre reinforced steel pile and structural steel pile design

It is clearly evident from the figure5.11 that the structure foundation of piles with respect to the different materials performs in different forms. It was observed that the pile foundation made up of carbon fibre mixed structural steel performed much better as compared to that of the conventional structural steel.

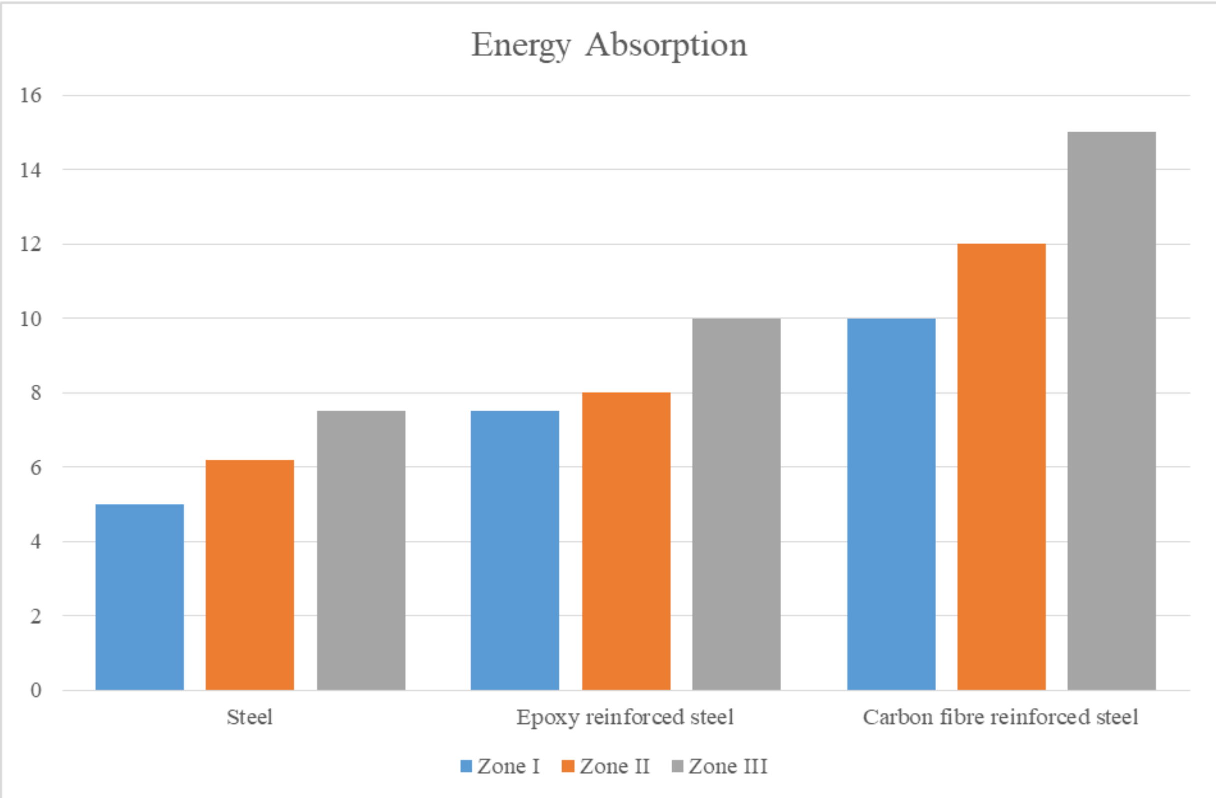

Figure 24 Structural performance of piles with different materials in different earthquake zones

It is clearly evident from the figure 5.12 that the structure foundation of piles with respect to the different materials performs in different forms. It was observed that the pile foundation made up of carbon fibre mixed structural steel performed much better as compared to that of the conventional structural steel and that of epoxy fibre reinforced steel. The structures were subjected to different forms of loading conditions with respect to different seismic loading conditions. Energy absorption characteristics and maximum deformation characteristics of the structure was performed and compared to each other under variable loading conditions to estimate the performance of the structure. It was observed that the energy absorbed by Carbon fibre reinforced structural steel absorbs the maximum amount and energy and undergoes less deformation. Therefore, Carbon fibre reinforced structural steel is superior in performance as compared to that of the structural steel and epoxy fibre reinforced structural steel.

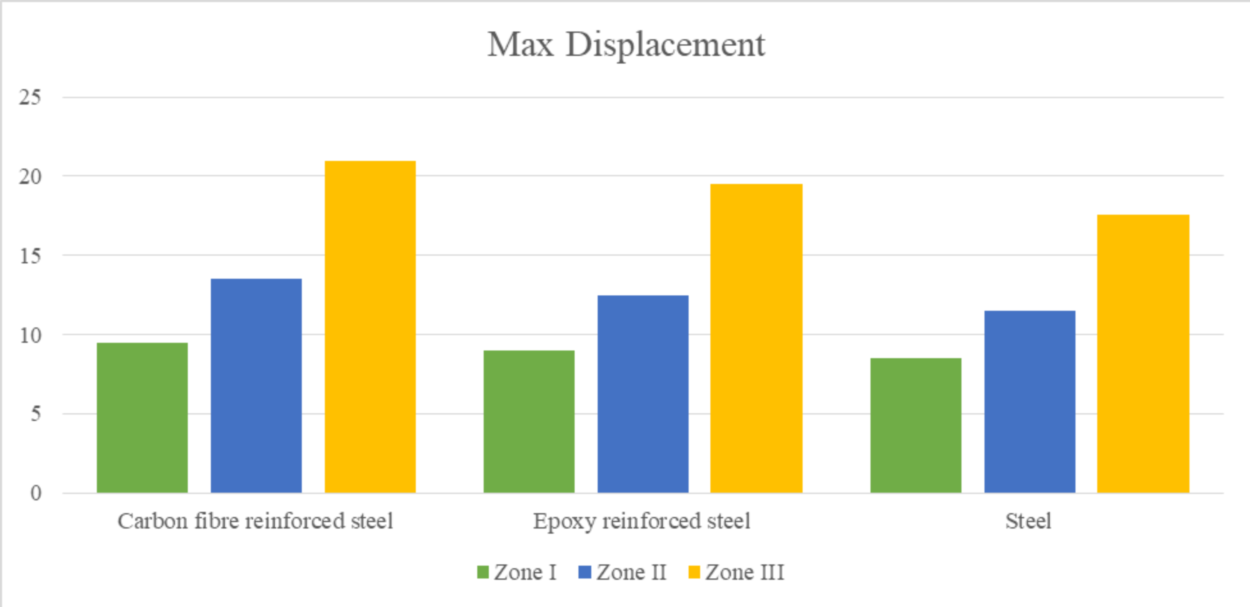

Figure 25 Structural performance of piles with different materials in different earthquake zones

6 CONCLUSION

The effectiveness of piling foundations for bridges against seismic loads has long been a significant issue. Design of the bridges under earthquake is impeded by a lack of interpretation and knowledge of the characteristics affecting the performance of bridge foundation structures under seismic loading. The creation of a numerical model that can accurately depict the earthquake phenomenon and do so at a low cost while simulating situations that real-world buildings would experience is crucial. Even though dynamic analysis is a laborious and time-consuming endeavor, practicality becomes crucial for a structure's performance and evaluation at its best. It is necessary to consider how different pile foundation materials for bridges respond to seismic loading conditions were monitored. Such an analysis was required to verify the performance of each structure acting under seismic loads. In this study, a numerical model is developed to evaluate both bridges and pile foundation performance with respect to varying seismic loading conditions.

- Carbon fibre reinforced structural steel is superior in performance as compared to that of the structural steel and epoxy fibre reinforced structural steel in both pile foundation as well as development of bridge structure.
- Carbon fibre structural steel pile foundation undergoes a maximum displacement of 9 mm, 13.5 mm and 21 mm respectively in Zone III, Zone IV and Zone V.
- Epoxy fibre structural steel pile foundation undergoes a maximum displacement of 8.5 mm, 12 mm and 18.5 mm respectively in Zone III, Zone IV and Zone V.
- Structural steel pile foundation undergoes a maximum displacement of 7.5 mm, 11 mm and 17 mm respectively in Zone III, Zone IV and Zone V.
- Factor of Safety of the structural steel bridge structure was found out to be minimum of 2.1 which will be considered at the situation of the seismic load. Furthermore, the carbon fibre reinforced steel structure and epoxy fibre reinforced steel structure will have factor of safety of 3.8 and 3.1.
- Maximum nodal displacement for bridge structure with respect to seismic load conditions for different materials were Carbon fibre structural steel as 63.104 mm, Epoxy Fibre structural steel as 69.992 mm and Structural steel as 70.091 mm respectively.

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